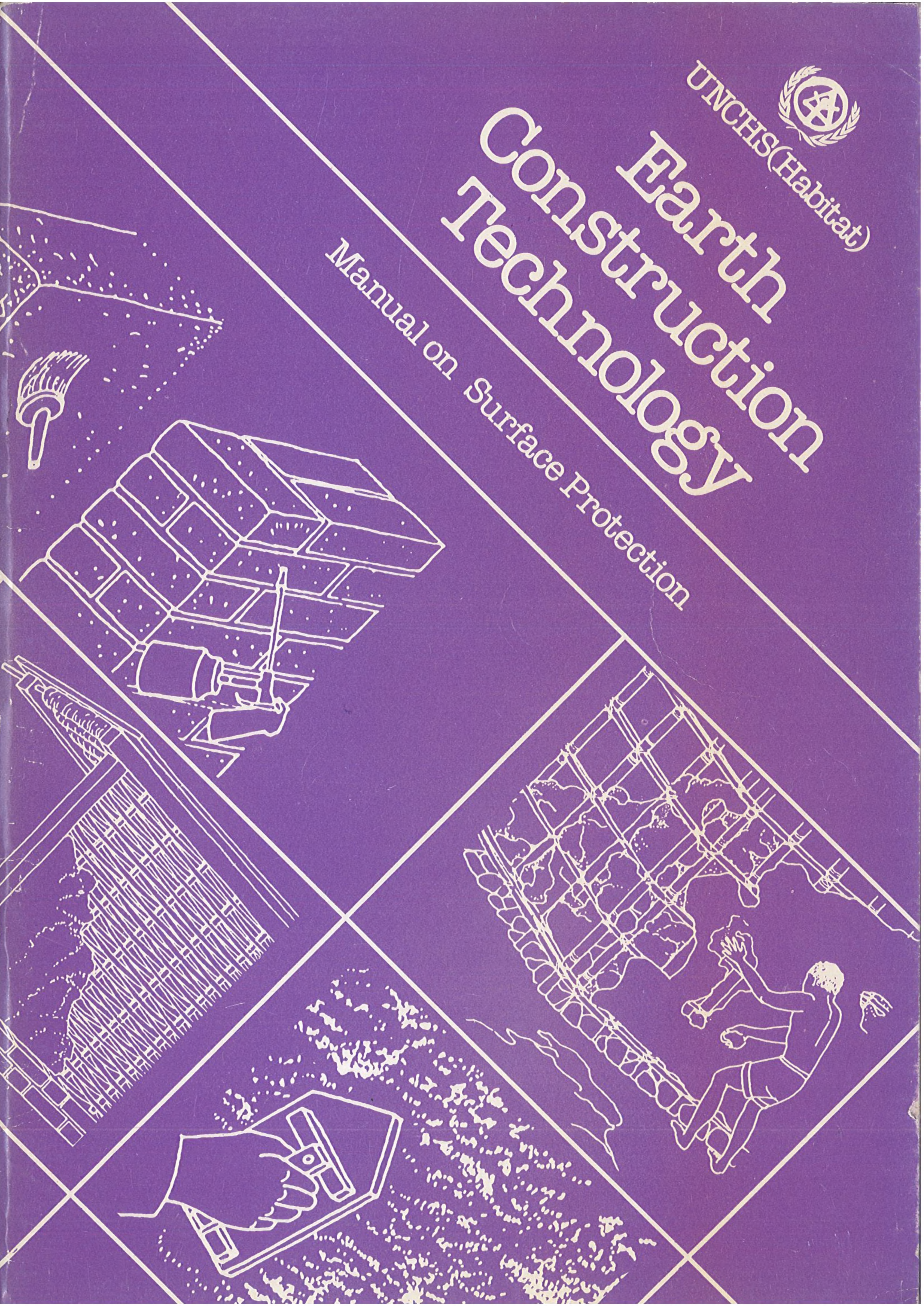
UNCHS (Habitat)

Earth Construction Technology

Manual on Surface Protection



EARTH CONSTRUCTION TECHNOLOGY

MANUAL ON SURFACE PROTECTION

United Nations Centre for Human Settlements (Habitat)
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FOREWORD

In most rural areas of the developing countries and in some urban low-income settlements, earth is the main material used for shelter construction. Under these circumstances, earth construction is characterized by dilapidated, temporary and unsafe structures. In fact, living examples of good, durable and attractive earth buildings are hard to come by, while the popularity of the material has dwindled to the extent that, even in circumstances where it should be the obvious choice in rural housing construction, preference has been given to relatively modern materials.

In principle, soil is not restricted to low-cost construction, but, rather, forms the basis of a technically sound engineering practice which is comparable to concrete technology or that of any of the popularly adopted building materials. Ultimately, a building material responds to clearly defined functional requirements in the construction process. The merit of earth in construction should be judged by its ability to fulfil a number of construction tasks - notably as a material for walls, floor, renderings and even for roofs. The issue of earth being a low-cost material is incidental and, indeed, an added advantage to these technically viable properties. For this reason, the material should be promoted alongside other conventional materials to the extent that professionals in the construction sector can make a choice for earth in preference over or as an alternative to comparable materials. It is along these lines that the objectives of wide-scale adoption of the material could be achieved while meeting the construction needs of the low-income population.

Following this principle, earth construction faces an obvious disadvantage in comparison with other popularly adopted materials. There is limited knowledge of good earth construction practice. The construction technologies which are predominant in the informal channels for artisan training are defective and inappropriate. In the conventional technical and professional training institutions, there is hardly any coverage of the subject of earth construction apart from basic civil engineering consideration. While architects, town planners, civil engineers, quantity surveryors and numerous sub-professionals in the construction sector have a role to play in promoting the use of earth, the foremost task is to fill a gap in their knowledge, i.e., to provide adequate technical information on earth construction for use by professionals in field implementation projects. It is for this purpose that this set of publications has been provided.

This series of publications on earth construction is made up of four technical manuals, namely, (1) Manual on basic principles of earth application, (2) Manual on production of components, (3) Manual on design and construction techniques, and (4) Manual on surface protection. The four manuals are complementary to each other yet

each is presented in a distinct and concise manner to respond to a specific component of the subject.

These manuals are intended for professionals dealing with projects on earth construction and should serve as useful reference material and aids in actual field practice. This current publication will be supplemented by other publications on various aspects of earth construction for the benefit of a wider group of professionals, programme administrators and policy-makers who are concerned with the subject. Eventually, it is expected that all these efforts will contribute to the provision of detailed and simplified manuals for use by the ultimate field worker - the technician or the craftsman.

The preparation of these manuals is based on an extensive project on earth construction technology undertaken by UNCHS (Habitat) in collaboration with the Government of Belgium. UNCHS (Habitat) is deeply grateful to Messrs. Hugo Houben and Guillaud Hubert, who were the principal consultants for the project.

Dr. Arcot Ramachandran
Under-Secretary-General
Executive Director

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I. BASIC CONSIDERATIONS

The very large majority of the world's earth dwellings, built for the most part in rural environments, all suffer from the same defects when exposed to bad weather: surface erosion, partial crumbling, unhealthy conditions because of constant humidity, walls hollowed at their base, etc. It is thus extremely desirable to propose effective solutions for their restoration and protection. These solutions can moreover be applied to homes which are still sound but which are liable to deteriorate if not effectively protected. Furthermore, it would be best if these solutions were integrated into current or future construction in earth so that these typical defects could be banished forever.

Apart from this, a coherent and truly feasible revival of construction in earth can hardly be envisaged if the material does not satisfy requirements as well as other modern materials. This objective will be attained by improving the material itself and the construction techniques involved as well as by using a wide range of techniques which can bring about a marked reduction in the sensitivity to water of earth surfaces.

Like other surfaces in modern materials, earth surfaces must be capable of being given protective coatings which meet current specifications for wall facings. Earth will only enjoy a qulaity image when it is regarded as a truly modern material. The necessity of protecting the earth used in the structure, long before being approached at the level of surface protection, remains subordinate to the quality of the material, design, and the construction procedures used for the structure. Between the stabilization of the material and the systematic employment of non-eroding rendering - the

two most common approaches adopted - the range of solutions for the protection of surfaces is sufficiently wide to ensure durability, without having to resort to "miracle cures". However, of the numerous structures examined, stabilization and rendering only rarely appear to be satisfactory, and do not always provide a lasting solution.

A. The need to protect

Every wall built of earth should be able to stand up to damp and the direct action of water. The ability of an earth wall to withstand water is above all dependent on the quality of the soil itself, its grain-size distribution, structure, and porosity. It can be improved by adding a stabilizer under controlled conditions, or protected with protective coatings compatible with the material, or by taking protective measures in the design and construction states, such as broad eaves, porches, and so on. The protection offered by renderings can take many forms, and varies considerably from region to region as regional conditions impose specific protection requirements on the material.

Generally speaking, in temperate regions, when the soil is of a satisfactory quality, earth walls stand up to weather erosion insofar as they are built on good foundations or footings and are protected at the top. If the soil is of moderate quality, stabilization can bring some improvement without, of course, neglecting the basic protective measures at the top and the bottom of the wall. In dry climates, earth walls protected at the top by an edge of the roof, or some other "hat", stand up well to water, if they are not liable to flood damage. In any region where rainfall is low, or medium, protection against rain can be afforded simply by

taking architectural precautions. In contrast, in regions with high rainfall and driving rains with a virtually level trajectory (e.g., in the topics), protective coatings are virtually indispensable. This precaution is essential in regions where climatic vicissitudes go hand in hand with an architectural tradition which provides no protection either at the top or the bottom of the wall (e.g., mud architecture in the Sahel). Similarly, coatings may be more or less necessary depending on the construction technique.

Thus, for monolithic soil walls (e.g., cob, rammed earth, clay-straw) which are suitably protected and uncracked, the need of protection is less than for walls in earth masonry (e.g., adobe, compressed blocks) where the water may penetrate at the brick mortar interface, i.e., the joints.

In principle, protective coating is not necessary for well-built structures in stabilized soil. Stabilized earth walls stand up well to bad weather for many years. Good base courses are, however, not pointless. It can be expected that a soil wall which is unprotected at the top will start to undergo local deterioration. The protective covering may thus be useful when the need becomes apparent, several years after construction. Even so, the decision to protect the surface may be influenced by specific conditions relating to the use of the rooms and subsequent maintenance.

When it is decided to use a coating, an effort must be made to obtain the smoothest and finest outer surface possible. For example, with rammed earth, stones will normally be placed in the centre of the wall and the outer surfaces rammed slightly

more. When it comes to providing a surface dressing, the stones will be concentrated on the outside edge of the wall and the wall may be less rammed in order to obtain a slightly open structure. After a first season of exposure to the elements, the stones will be exposed and will facilitate the adhesion of the rendering. In this case, the middle and the inside surface of the wall will be strongly rammed in order to provide the necessary strength.

Prior to deciding on the use of surface protection, three alternative solutions should be considered:

(a) Building a well-designed structure, either provided with good foundations, and an anti-capillary barrier, overhanging roofs, gutters and downpipes, with good drainage and protected against the wind, and constructed according to the rules of the art;

(b) Stabilization, avoiding, if possible, stabilizing all the material (excessive cost) and limiting the stabilization to the outer surface of the walls; or by stabilizing the waterproof coating (wash, or distemper), rather than in the thickness of the wall;

(c) Application of a coating several years after the wall has become less smooth, giving good adherence. The deterioration of the surface of a wall in earth is in fact very rapid in the first two years but stabilizes very rapidly.

It is above all advisable to protect structures against wind as this, associated with rain, can be particularly corrosive, even with very brief and short squalls. Finally a coating which is not suited to the earth, or which is ineffective because it has been poorly executed, can be more harmful than if it had not applied at all.

B. Functions and requirements

The main functions of a protective coating are the protection of the wall against bad weather and impact, the extension of the service life of the walls, the improvement of their appearance by hiding imperfections in the rough work, and giving walls an attractive colour - without, however, masking defects - and improving thermal comfort.

These functions should not allow the cost of the coating to get out of hand. The functions may result in contradictory requirements. For example a good coating should be impermeable to rain outside the structure but remain permeable to moisture from the inside. Renderings are very susceptible to climatic stresses (variations in temperature, sun, rain, and frost) and may deteriorate. However, they must not lead to the irreversible deterioration of the support (e.g., loss of wall material stuck to pieces of rendering).

A good protective coating should adhere well to the support without provoking the loss of wall material, be flexible in order to allow for the deformation of the support without cracking, be impermeable to rain, be permeable to water vapour in the wall itself, be frostproof, and, finally, have a colour and texture compatible with the local environment.

C. Deficiencies in earth walls

The numerous symptoms of the deterioration of soil walls are related to the influence of local climatic conditions, such as rain, frost, and great heat, as well as lack of maintenance, lack of knowledge about how to improve deteriorating walls and mechanical shock. Observations of renderings indicate that: either the renderings are in good condition - they can be old and well-maintained, or new (less than five years old) and recently applied - or they are in poor condition - they may be very old, 50 years or more, and their durability praiseworthy, compared with modern renderings. These are usually renderings based on non-hydraulic lime. New renderings in a poor state are often in a very bad way after no more than five years, the shortest period possible in which a rendering can be evaluated. These are often cement renderings.

Cement displaces the accumulated know-how acquired with older rendrings, so that although it may have remedied certain problems (e.g., speed of application, reliability), it does not really provide a lasting alternative. The loss of traditional know-how and the absence of modern know-how is thus often a major cause of deficiencies.

The same applies to the maintenance of dwellings. Formerly, renderings were considered more as wearing layers which had to be regularly maintained (e.g., refreshment of washes). Now it seems that home maintenance is slowly disappearing as a social custom in the majority of rich countries. The shift is due to the excessive confidence in certain products (e.g., cement, paints).

In many of the developing countries, maintenance of structures continues to be a significant social link in the community. The festive regular renewal of the rendering of mosques in Mali, with the whole village taking part, is a good example.

1. Deficiencies and their causes

Conventional symptoms may range from a simple dirty streak (marring the appearance of the structure) to a change in composition. The main deficiencies are poor composition, a lack of flexibility or poor adhesion to the support, and poor waterproofing. The reasons for these defects include the use of unsuitable materials, careless application, structural tension, a lack of maintenance and a defect in the supporting structure, such as subsidence, and cracking.

2. Symptoms

Defective renderings on soil walls are revealed by the fairly typical symptoms discussed below.

(a) Crumbling

The rendering can be easily scratched with a fingernail and disintegrates. It is mainly seen in accessible places such as the reveals of doors and windows.

(b) Erosion

Eroded renderings are thin and no longer protect the wall. The erosion may be even and the increasingly thin rendering tends to disappear. Erosion may also be localized and the rendering may be left as isolated patches.

(c) Crazing

The surface of the rendering deteriorates into an infinity of threadlike cracks, permitting the access of water.

(d) Cracks

These may be few in number but gape or be very numerous and more or less closed. Fine cracks or crazing may develop into larger cracks. There is a danger of penetration by water and frost.

(e) Blistering

This may be localized or be overall swelling of the rendering, and is visible as a bump or series of bumps. The surface of the wall sounds hollow because the rendering is no longer attached to the wall. There is a danger that pieces of rendering may fall off the wall.

(f) Blowing

The rendering is pitted with small craters with a diamter of no more than 20 mm and of variable depth. Blowing occurs quite often on lime-based renderings. There is a danger of water penetration and frost damage.

(g) Efflorescence

The rendering is discoloured by small white or grey rings. These are crystalline or amorphous deposits of an alkaline or alkaline earth character and include sulphates, carbonates, and nitrates. These accretions of salt may bring about the disintegration and loosening of the renderings.

(h) Infiltration

Water is trapped in the thickness of the rendering resulting in the appearance of efflorescene or in triggering off cracking and loss of adhesion. Once this has started the rendering may disintegrate very rapidly.

(i) Dark patches

These may appear in the form of black or brown patches. They are the result of the decay of organic matter left after water has dried up or by a localized flow of water.

3. Mechanisms

(a) Expansion

Frost or alternating wetting and drying can cause clay fraction to expand at the wall/rendering interface. If the rendering is too rigid, it will first crack and then crumble. Similarly, on a heterogenous wall (e.g., large stones isolated in rammed earth) differences in the thermal expansion of the soil and the stone can cause localized failure.

(b) Shrinkage

When a rendering first dries it shrinks, putting the material under stress. There may be loss of adhesion and loosening. This happens when a rendering is too rigid and the support is too smooth. When the support is rough, the same rendering can cause cracking. The cracks may be clearly visible and few in number when the adhesion is low, or numerous and fine when adhesion is high. The thicker and stronger the rendering, the wider will be the cracks. They appear on the outer face of the rendering if the contraction is the result of exposure to wind or sun.

Cracks may also develop at the interface and advance towards the outer surface on dry walls which contain little water, resulting in capillary suction operating from the rendering/support interface. The most sensitive spots are recessed corners and the angles around bays.

(c) Vapour pressure

Water vapour may accumulate in the form of condensation at the rendering/support interface. Blistering may be observed, heralding detachment. This phenomenon is typical for maritime and temperate climates where internal vapour pressure

is higher than external vapour pressure. This differential pressure causes the vapour to migrate through the wall and the rendering. These must be permeable; waterproof or excessively thick renderings should be avoided. The opposite problem - internal condensation - may arise in tropical climates or in air-conditioned rooms.

(d) Others

Other mechanisms are the infiltration of rainwater or drips entering via cracks (accumulation of damp), the use of unsuitable materials (poorly slaked lime, old cement), efflorescence caused by moisture or excessive smoothing of the rendering (appearance of laitance on the surface), attack by micro-organisms (lichens, algaes, mosses), and plants (creepers, ivy), sloppy application (poor preparation of the mortar or support, frost or very hot conditions), rain erosion, wind erosion, and damage due to mechanical impact.

D. Good practice

The main defects which can be observed in renderings are due to:

(a) Incorrect composition of renderings and defective constitution;

(b) Hasty application, and a failure to respect the fundamental rules of the art;

(c) Poor site conditions;

(d) Incorrect or sloppy application;

(e) Taking heed of good practice, know-how, and the literature is absolutely essential. Moreover, the application of lasting renderings to earth walls demands special care and attention. The most essential support, and the use of binders which are not too strong and which result in fat and plastic mortars.

1. Constitution of renderings

Single-coat renderings should be avoided, as they are too thick and too dense. Renderings based on mineral binders (lime, cement, and clay soils) should be applied in several coats, at least two - with an uncracked second coat - and preferably three, with a render, float, and set. This application in three coats is particularly important for conventional lime-based and cement-based renderings, the thickness of which diminishes with the float and the finishing coat.

(a) Render

This is the first coat applied to the support and provides the support for the float. It is made of a fairly fluid mortar, generously provided with binder, and very finely ground. It is energetically applied with a trowel and to a well-prepared support. Its thickness ranges from 2 to 4 mm and the surface has rough appearance.

(b) Floating coat

This is an intermediate coat which takes up any unevenness in the support. It gives the rendering its solidity and impermeability while staying permeable to migrations of water vapour. The floating coat is applied two to eight days after the render, in one or two layers, and has a final thickness of between 8 and 20 mm. The floating coat will have no cracks and is level to the float. Application in several layers (if possible) makes it possible to plug fine cracks in the underlying coats. The amount of binder used is less and finer sand is used. The floating coat is grooved with the trowel or with a brush to improve the adhesion of the finishing coat. The curing of the floating coat must be perfect.

(c) Finishing coat

This coat finishes the protective rendering and plugs any cracks in the floating coat. It is the decorative coat, both with respect to colour and texture. The finishing coat has the lowest binder content, as no cracks at all can be tolerated. Care should be taken that the finishing coat is not compressed too much with the float, because of the danger of causing the moisture to come to the surface and of crazing. This is the coat which may have to have to be redone from time to time.

2. When to apply

An earth wall should never be rendered before:

(a) Shrinkage has stabilized; this may take several weeks or several months. Times may be six to nine months for thick rammed earth, three or four months to a year for monolithic walls in cob or clay-straw; and within a year two to three months at least of building for adobe or compressed block walls;

(b) Any settlement in the wall has taken place; the carcassing must therefore be complete, including any loads due to floorboards and the roof;

(c) Migration of water and moisture vapour due to drying has stopped. The internal core of the wall should not contain more than 5 per cent water by weight, and this can be a guide to when to start rendering works. Weather conditions when the work is in progress play an essential role.

3. Conditions of application

Do not render in excessively cold weather nor when it is very hot. Avoid working in driving rain as well as in sun and violent wind, and when it is very dry. The best climatic conditions are when it is moderately warm and slightly humid.

Make horizontal and vertical joints with a view to completing panels of 10 to 20 m^2 in size in one go. Walls should be finished on the same day as they are started.

Pay particular care to intersections, and reveals in bays. Where the support changes (e.g., earth and wood) the rendering should incorporate reinforcement at that point. Do not continue the rendering to ground level (capillary action), rather make a joint at the level of the floating.

Avoid the excessively rapid drying of the rendering by spraying water on the surface (morning or evening), by hanging up protective sheets against heat and rain action which could wash off the rendering. Keep the environment humid.

Make sure that the ingredients (binders and sands) are of good quality and that mixing is properly carried out.

In warm climates, it is advisable to apply a wash to the rendering about three weeks after application, in order to plug any cracks.

4. Application techniques

Application should be done by hand, for earth-based renderings. Balls of mortar are thrown energetically against the wall and then smoothed with the palm of the hand, avoiding excessive finger pressure.

When using conventional tools, trowels, floats, excessive compression should be avoided.

Use should be made of a brush or broom for a liquid render coat, with an adjustable hand-operated plaster blowing machine to give a Tyrolean finish.

With a pneumatic blowing machine or rendering pump, make sure that the blowing pressure can be regulated so as to be neither too strong nor too weak.

5. Preparation of the support

This preparatory phase in applying the rendering must be carried out with particular care.

(a) Dust removal

The support must be free of all loose and crumbling material, and dust. It must be carefully rubbed down and brushed with a metallic brush.

(b) Moistening

The support must not absorb the water contained in the rendering, as this may hinder setting and reduce the adhesion of the rendering. The support must therefore be moistened in order to avoid capillary suction, but not too mcuh as a film of moisture could be created which reduces adhesion. The support should have a dull appearance, that is to say sprinkled until the wetting agent flows off. This operation may require various applications of water.

A distinction is made between supports stabilized through-and-through or only on their surface

(moisten until rejection), and unstabilized supports, which should hardly be moistened at all (risk of causing the clay to swell). On non-stabilized supports, an impregnating wash can help create cracks to support the rendering.

(c) Anchoring points

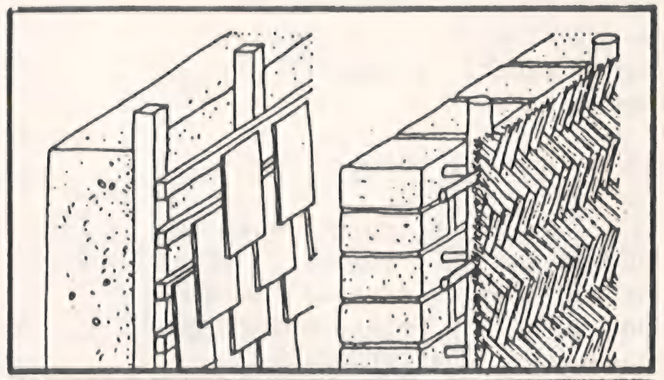
On brickwork the joints must be roughened with a jointer. With rammed earth, brushing reveals the stones. Good anchoring points ensure good adhesion of the rendering.

II. SURFACE PROTECTION

A. Types of surface protection

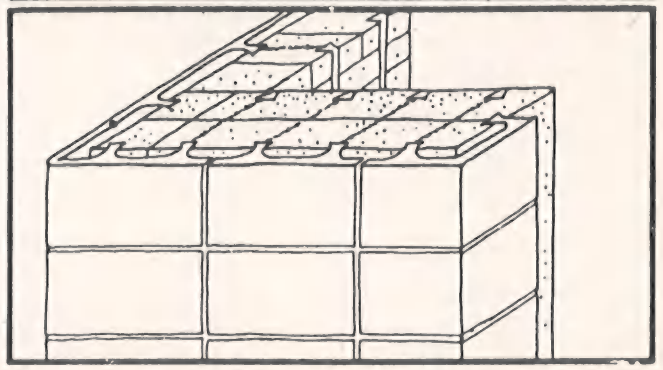
1. Weather boards

These are coverings attached to the wall and fixed to a secondary structure in wood or metal. Weather boards may be in any of a variety of materials, such as slabs of wood, planks, boards, tiles, cement-fibre elements, corrugated iron, external insulating systems, and so on.



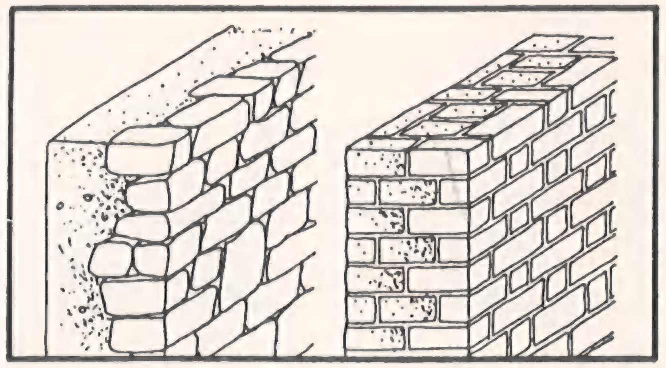
2. Cladding

Walls made of earth blocks and a cladding of prefabricated concrete elements were used in Germany in the 1920s. Both the earth and concrete products must be extremely well produced as design tolerances are very limited.



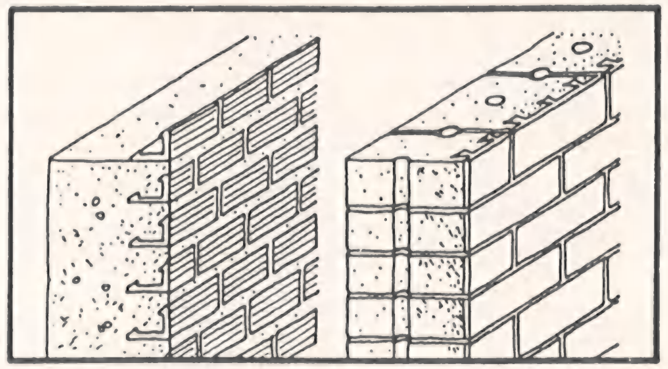
3. Facing

This protective procedure was known to the Mesopotamians, who applied glaxed ceramic cones to the facing of the wall when still wet. The development of this system has been towards pebble and burnt brick facings, common in the Asian and Pacific region. The facing is applied while the rammed earth wall is still in the shuttering, or applied subsequently. The system may result in a mixed wall, the strength of which is not always uniform, and which may result in unequal subsidence of the wall and revetment-facing. The system is not suitable for use in earthquake areas.



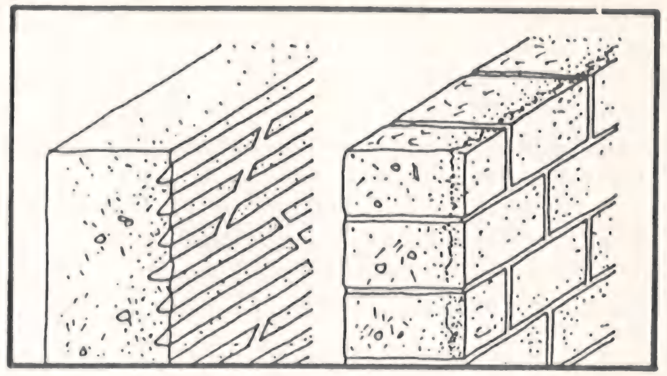
4. Integrated facing

Burnt clay elements which are either flat or "L" shaped are fitted as facing on the rammed earth wall during construction or are included in the earth block during moulding. In the latter case, the adhesion of the facing to the earth block is ensured by dovetail fittings.



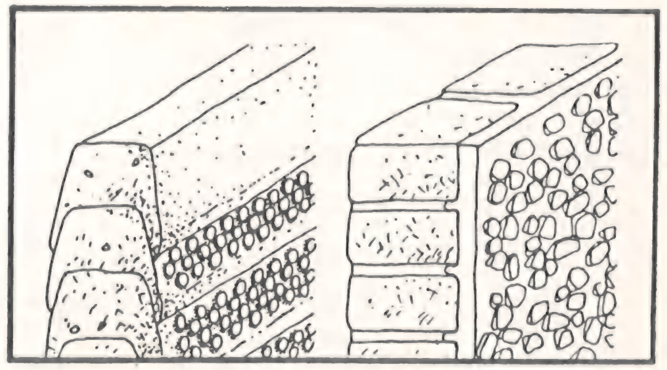
5. Twin layers

This is a surface stabilization system. With rammed earth this can take the form of the stabilization of the entire outer surface, while still in the formwork, or partial stabilization with layers of mortar or lime. The twin layer system has also been developed for soil blocks (Burundi, 1952, and EIER at Ouagadougou). It gives excellent results but is slow in production. The effect of the surface stabilization is limited to a thickness of 2 to 3 cm.



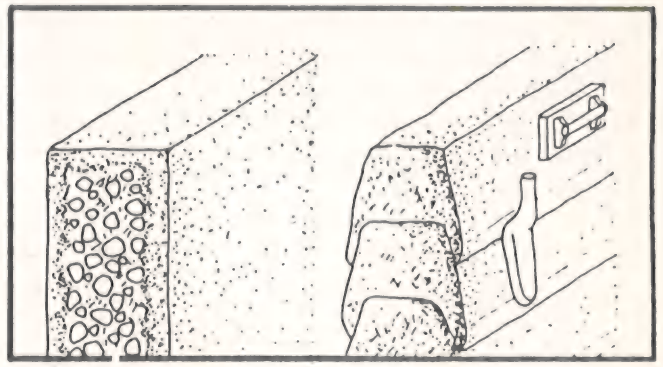
6. Inlay

Here an outer wearing layer is made from inlaid elements which can range from pebbles or flakes of stones, potsherds or brick flakes, shells, bottle tops (seen in Mexico), bottoms of bottles and box tops (seen in Khartoum). The work is demanding and requires a large supply of the elements used. Only the most exposed walls are inlaid.



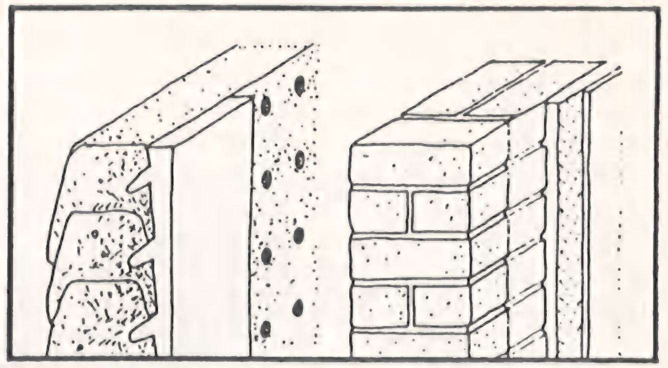
7. Surface treatment

The exposed surface is carefully treated. French builders in rammed earth (<u>pisé de terre</u>) finish the wall with <u>fleur de pisé</u>. This involves the careful ramming of the outer surface with an extremely fine soil. The surface treatment may also be the finishing of the wall with a wooden paddle, as practised in Morocco. Such external tamping is also carried out in Yemen on cob structures. The surface of the wall can also be rubbed down with a stone for example. Such treatments reduce the porosity of the soil and are effective but should not be carried out when it is intended to apply a rendering.



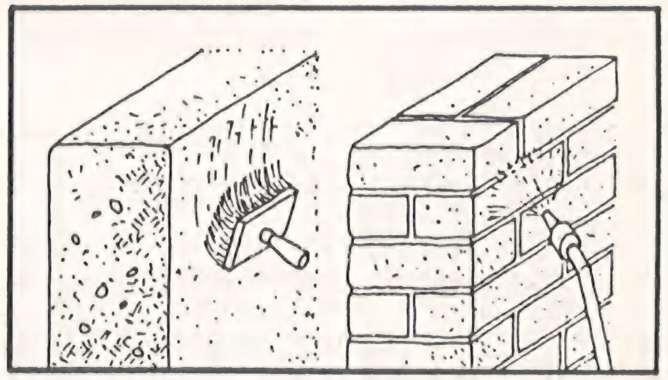
8. Renderings

These may be in earth, stabilized earth, or a sand-based mortar to which a hydraulic binder has been added: cement or lime, or some other additive such as bitumen, resin, etc. Renderings can be applied in a single thick or thin layer, or in several layers. Multi-layer renderings perform extremely well but takes longer to apply.



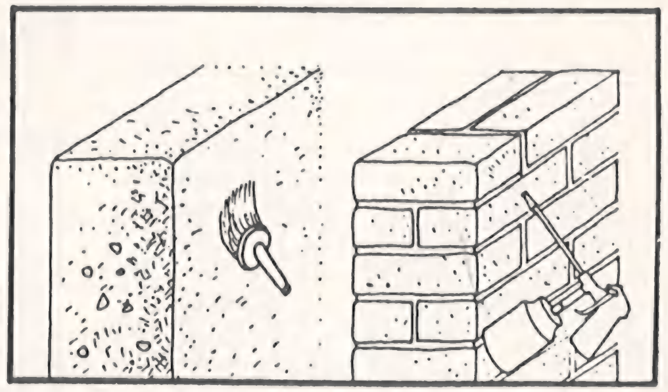
9. Paint

The coatings mentioned under this heading include conventional paints, and distempers and washes. The latter are cement or lime slurries applied with a brush on walls properly prepared and hydrated in advance. It may also be bitumen applied in the form of a liquid cut-back. A spray-gun may be used to apply them.



10. Impregnation

The soil is impregnated with a natural (e.g., lin-seed soil) or chemical (e.g., silicon) product which confers certain qualities on the wall: impermeability, fixing of fine grains and powders, hardening of the exposed wall surface, colouring, and so forth. The impregnating product is applied with either a brush or a spray.



B. Renderings

The conventional renderings, based on hydraulic binders such as cement and/or lime, plaster, and with or without additives, are well-known. When employed for the protection of earth buildings, this type of dressing often gives adequate results, but numerous precautions must be taken. While these materials are often used with success, disappointments are also frequent. These failures appear to be mainly the result of the use of incorrect amounts of material and in particular a lack of know-how. Apart from the proportions used in mixing, which must be correct if the rendering is to be flexible and if it is to allow the passage of water vapour, problems often arise from the poor preparation of the support and careless application. The rendering and the soil must be compatible and the greatest care should be taken in choosing the ingredients, the proportions in which they are mixed, and the techniques used to prepare the wall and apply the rendering.

1. Alternative plasters

(a) Non-hydraulic lime

The best results are obtained with hydrated slaked limes, in the form of extremely fine-ground powder or a paste prepared beforehand. The use of slaked lime as a surface rendering for soil structures is old and well-established in many countries. The hardening of a rendering based on slaked lime is the result of slow carbonation by carbon dioxide in the air, and as a result the dressing should not be too sheltered. The long-hardening process makes these renderings sensitive to atmospheric conditions, particularly frost and great heat.

In many regions, lime dressings are modified during preparation, with various additives which can improve their quality. For example fresh bull's blood, leaving aside its importance in magical practice, improves

the waterproofing qualities of the rendering. Other practices include the addition of natural soap which improves the workability of the mortar, facilitating mixing and application. In Morocco, lime renderings of the Takkelakt type, were traditionally lubricated with yolk of egg, although nowadays soft soap is used, which improves water-proofing and facilitates polishing. The addition of a little molasses helps to harden the rendering.

When slaked lime renderings are exposed to considerable stressing, a small amount of hydraulic lime or cement can be added. Only a small proportion is required to avoid excessive hardening or reducing permeability.

Experimentation has made it possible to specify proportions for lime or sand based multi-layer renderings and mixed renderings based on lime, cement and sand.

	Lime	Cement	Sand
1st layer	1		1-2
2nd layer	1		2, 5-3
3rd layer	1		3, 5-4
or			
1st layer	2	1	3-4
2nd layer	2	1	6
3rd layer	2	1	8

(b) Hydraulic lime

A distinction is made between natural hydraulic limes and artificial hydraulic limes. The natural limes have the qualities of lime and they harden rapidly with water and slowly in air. This advantage reduces the sensitivity of the new rendering to damp and frost. The artificial hydraulic limes have properties similar to cement and their use should be avoided. In small proportions they can be useful, e.g., 1 part lime to 5 or 10 parts sand.

(c) Cement

Cement mortars are too rigid and suffer from the defect of not adhering well to earth walls. Cracking, blow-up, and loosening in sheets are frequently observed symptoms. Their use is not advised and it can at best be a make-shift solution, with proportions of the order of 1 part to 5 or 10 parts. It is better to add a little lime to them: 1 to 1 or 1 to 2 if at all possible.

Cement renderings should be applied on a wire netting. This reduces cracking and breaking into slabs, but does not improve their adhesion.

(d) Gypsum (Plaster)

Plaster renderings are fairly compatible with soil walls but should be used inside rather than outside. In dry climate, they can be used outside as well. It is best to improve the adhesion of plaster to the earth by first applying a diluted wash of lime or cement.

On outside walls slaked lime be added to the plaster. This hardens the rendering and improves its water resistance. The rendering can be applied in two layers with 1 to 1.5 parts of slaked lime added to 10 parts of plaster and 7.5 to 10 parts of sand for the first layer. The same proportion of binder, but without sand, can be used for the second layer. Waterproofing the surface with a fluorosilicate solution after a period of a few days is desirable.

(e) Pozzolana

Added to lime, pozzolana, which contains enough silica, produces a compound similar to Portland cement. Pozzolana-based renderings are, however, far more flexible than cement-based ones. They are often used for finishing flat earth-brickwork roofs and for vaulting.

(f) Gum arabic

When added to soil, or even better to sand, gum arabic produces good protective coatings, which are hard, do not crack, and adhere well to earth walls. This product does not stand up well to water and it is therefore better to use it on the inside of the building. The colour obtained is a pastel red ochre. Gum arabic is used as a rendering chiefly in Sudan, but is becoming increasingly expensive.

(g) Resin

As knowledge stands at present the use of resins, organic binders, and various mineral substances should preferably be limited to finishing the renderings described above.

(h) Ready-to-use renderings

These renderings are prepared with an added dry mortar based on mineral binders. They are designed to be applied to other supports than earth walls. Their use demands technical and strict, systematic experimentation.

Combined systems such as mineral-organic products with an impregnation layer, finishing mortar based on mineral binders to which resins are added, and finishing layers using organic binders, are also worth considering, on condition that the basic principles applicable to all renderings for earth walls are respected.

(i) Plastic coating

The use of a plastic coating implies that the appearance of the support will not be preserved. The incorporation of reinforcement in waterproof plastic protection may be attractive, and depends on the configuration of the support. However, the danger of blistering and the impermeability to water vapour makes their use inadvisable.

2. Output and cost of plasters

These following figures are based on observations on large-scale sites in tropical countries. The outputs given are for qualified labour.

Preparation of the support, scraping and removal of dust	1/2 h per D per m^2
Preparation of the mortar + assistance to the mason	1/4 h per D per m^2
Application in 3 layers by the mason	1/4 h per D per m^2
Application of wash by 1 labourer	1/30 h per D per m^2
Supervision by a foreman	1/20 h per D per m^2
Total	1.1 h per D per m^2

Cost is not particularly dependent on the type of rendering but rather on the organization of the work. The following figures are for work carried by direct employees or by a co-operative. They are applicable for various sites and for both interior and exterior rendering.

Type of structure	Percentage of total cost without services
- 1 - Very low cost house	15
- 2 - Small house with a minimum of equipment	20-25
- 3 - "Carcase" dwelling	30
- 4 - Covering for vaulting and domes	5

For 1., the 15 per cent includes any incorporation of wire netting. The final price can be broken down as follows: materials 8 per cent; equipment 8 per cent; organization 8 per cent; pay 76 per cent. Labour costs can in fact reach 80 or even 90 per cent.

For 2., a minimum of equipment means no electricity, a single tap, a minimum of rooms, no floor protection, no drop-ceiling.

In case 3., the indicated value of 30 per cent is not unreasonable even when the dwellings are no more than carcases.

In 4., the covering is a damp-proofing coat.

C. Earth renderings

Earth can undoubtedly be an excellent rendering or be one of the ingredients of a rendering. Even so, earth is not a satisfactory basic component for first class exterior renderings, particularly in rainy environments, unless it is improved by the use of a stabilizing additive. Earth renderings have been widely used and still are in many regions of the world.

The adhesion of earth renderings, whether used inside or outside, is virtually perfect. They are, however, a wearing layer which is the first affected by erosion and which can be cheaply replaced. The simple application of impregnation, a wash or grout, or paint can considerably improve these renderings, which are somewhat fragile. The earth rendering is often referred to by the term "dagga", and the wide-spread employment of the term in the literature often leads to confusion.

(a) Earth

When used as a rendering, the earth is first rid of all elements of a diameter greater than 2 mm. Clayey

and sandy soils will preferably be used (1 part of clay to 2 to 3 parts of sand). Preliminary tests are advisable in order to determine exactly what value should be given to the 2 to 3 parts of sand. Such tests examine cracking and adherence a few days after application. Clays which suffer from strong swell and shrink are not suitable. Clays of the kaolinite type are preferable.

Lateritic clays often make good rendering in an attractive red or ochre. The main drawback of these earth renderings is that they are susceptible to cracking.

(b) Water

No great problems with mixing water are encountered. The most crucial factor is the amount used, which is important in controlling the shrink and drying of the rendering. Observation has shown that it is best to use rainwater.

Other improvements are also possible by adding deflocculants and dispersants to the water. By using less water and obtaining a dispersed and highly uniform mixture, the rendering will be less subject to shrink and thus will dry more quickly. The main deflocculants are sodium carbonate (Na_2CO_3) and sodium silicate ($Na_2O_xSiO_2$). Between 0.1 and 0.4 per cent should be added to the clay. Other products such as humic acid, tannic acid and horse urine can replace the water entirely.

(c) Fibres

Fibres act as reinforcement. Fibres can be of many differnt origins; vegetable, such as straw from wheat, barley, winter barley, rice, millet; animal hair and fur; on synthetic, such as polypropylene fibres. Common proportions are of the order of 20 to 30 kg of fibres per m^3 of soil used. In the majority of earth renderings 90 reinforced the fibres are cut to fairly short lengths.

The finishing layer can also be reinforced with fibres which give an atrractive texture to the rendering but which traps dust.

Fibres can also be added as a light filler, such as wood shavings or sawdust. Wood waste fillers should, however, be first mineralized by soaking in milk of lime or a cement solution.

(d) Stabilization

Virtually all products used for stabilizing soil in bulk are suitable for preparing renderings.

(i) Cement stabilization

This is only really effective if the soil is very sandy. Proportions may vary from 2 to 15 per cent of cement, depending on whether a mild improvement or true stabilization is desired. Cement-stabilized renderings should by preference be applied to stabilized surfaces.

It is also possible to add between 2 to 4 per cent of bitumen. This mixture tends to darken the dressing without spoiling the colour, but greatly improves water resistance.

(ii) Lime stabilization

Lime stabilization has its greatest effect on clayey soils when it is used in large quantities, often over 10 per cent. Similarly, a lime-stabilized rendering is best applied to a stabilized surface.

The addition of animal urine or dung can have truly astonishing effects on the rendering (less shrink, greater hardness and good permeability). The main drawback is the strong ammonia smell during mixing, which may upset some people.

(iii) Bitumen stabilization

Bitumen-stabilized soils should be neither too clayey nor too sandy and dusty. The quantity of bitumen ranges from 2 to 6 per cent. They are usually cut-backs which should be heated without exceeding 100°C. Where bituminous emulsions are used the mixture must be made slowly in order to avoid any breakdown of the emulsion.

The stabilizer can be prepared by adding four parts of bitumen to 1 part of kerosene, followed by heating and adding 1 per cent paraffin wax. The kerosene can be replaced by coal creosote. The mixture described above can be replaced by 4.5 parts of cut-back or 3.5 parts of bitumen emulsion.

Bitumen stabilization for renderings is particularly effective on soils which have already been reinforced with straw or even with dung. The bitumen is added only at the end, two to three hours before the rendering is applied. Mixtures of asphalt, gum arabic and caustic soda solution are also highly effective.

The support should be properly prepared, brushed and moistened. Excellent results have been obtained with this type of rendering by the CBRI at Roorkee in India.

(iv) Natural stabilizers

These are highly diverse and often are the traditional stabilizers in numerous countries. Their effectiveness is extremely variable. Their effect is more the retarding of the decay in the material, without really ensuring the sustained lifetime of the rendering, but limiting the frequency with which it is remade.

Traditional stabilizers include the juice of the agave and the opuntia cactuses, melted shea (karité) butter, often added to grum arabic; the juice from boiled banana twigs; 15 litres of rye flour boiled in 220 litres of water, with the paste obtained being added to the soil; cowpats or horse droppings (1 part dung to 1 part clay and 5 to 15 parts of sand); gum arabic, which forms colloids with water; the sap of the fruit of the acacia scorpiodes (gonahier) boiled in water with several pieces of limonite (a type of laterite), which results in a rather effective water repellent; euphorbia latex precipitated with lime, the sap of the néré; and peulh soap, a sort of casein, thinned and beaten like a paste. Other natural products have been tried at the Cacavelli Centre in Togo for the improvement of renderings. These include kapok oil obtained by roasted kapok seeds to obtain a powder form with a high lipid content. The powder is diluted with water and boiled for several hours. This is then mixed dry with the water, mixing water being added subsequently. The rendered wall is then distempered with two coats of kapok oil. Calcium palmitate, obtained by mixing fat lime and palmitic acid - a product obtained by reacting HCI with a native soap known as akoto - can also be used. The calcium palmitate is diluted in a small volume of water and the soil is mixed with the milk of lime obtained (10 per cent by weight of the mixture). The Hausa of Africa use natural potash, or an infusion of carob-bean husks, or even of mimosa which the richest people import from Egypt. Without a doubt there are a great many other natural stabilizers.

(v) Chemical stabilizers

There are numerous chemical stabilizers and their effectiveness has as yet not been scientifically confirmed. These include the celluloses, poly-vinyl acetate, vinyl chloride, the acrylics, sodium silicate, the quaternary amines, aniline, bentonite, soap stearates, casein glues, and paraffin. Others may be combinations of the above with, perhaps, the addition of natural products.

(e) Application of earth renderings

When used indoors earth renderings give excellent results, although it is advisable to strengthen weak points of the building with a mortar of sand and lime (internal and external corners, reveals, the bottom of walls).

Outside, a single layer is not enough. At least two layers should be applied, and preferably three. First apply a rough-cast in a highly adhesive clayey soil which can be finished with a mortar consisting of one part lime and one part sand; followed by 1.5 cm thick layer of pargeting in clay soil and coarse sand, reinforced with fibres chopped to 3 to 5 cm long, and finished with a top layer in clayey soil and sand, to which a light filler has been added (e.g., chaff or flax).

D. Paints and sealers

1. Opaque paints

The range of commerically available paints is extremely wide. When ordinary paints are used to protect earth walls they give satisfactory results at first. Very quickly, however, deficiencies such as blisters and loss of adhesion become apparent. Thus paint cannot be regarded as a means of giving a soil wall a lasting finish. Nevertheless, they afford temporary protection pending proper repair. Their use can be permitted indoors and for outside walls which are very well sheltered from the attack of the natural environment. Even so, it is preferable to use them as a complement to the finishing layer of the rendering. The surface which is to be painted should be absolutely dry and all dust removed with a brush. Moreover, primers which penetrate deeply into the material give poor results. It is better to apply an impregnating layer, either in linseed oil, or in a very dilute lead-based paint, applied at a rate of 0.50 l per m^2. When applying the two finishing coats, the best course is to consult the paint manufacturer for his technical advice.

When walls are stabilized in bitumen, it is advisable to apply two to three layers of paint to avoid bitumen exudations.

When all conditions are favourable, i.e., good quality paint, proper preparation of the support, and good application, the paint may last between three and five years.

American experiments have shown that better results are obtained on sandy earth walls rather than on clayey ones.

(a) Industrial paints

Aluminium-based paints do not hold well when applied directly to earth. They may be applied to undercoats treated with bitumen or to bitumen-stabilized walls.

Casein-based paints give fairly satisfactory results on earth walls.

Primers can be used to impregnate the surface.

Lead-based paints can be used on a surface treated with linseed oil.

Oil-based paints perform only moderately.

Polyvinyl acetate emulsions can sometimes be satisfactory.

Water-bound distempers should not be used on crumbly walls.

Latex paints are quite efficient on stabilized soil walls.

Resin-based paints often give satisfactory results, but silicon paints are not very reliable.

Acrylic paints breathe, are elastic, water repellent, and stand up well to the alkalinity of earth walls.

Watertight paints, alkyds, epoxies, and polyurethanes are to be avoided because they retain moisture.

Chlorinated rubber-based paints, which are elastic, and stand up well to heat, ultra-violet radiation and atmospheric conditions, can be used to waterproof roofs but should not be used for soil walls.

(b) Oils

Earth walls are an extremely porous support and absorb large amounts of non-oxiding oils, such as sump oils. However, they do not perform satisfactorily as the impregnated layers should not go too deep.

Linseed oil oxidizers, reacts with air and becomes fixed. It is only slightly soluble in water and can be applied to moist soil. It is a very satisfactory primer for lead and oil paints, but is expensive.

Castor oil has the same properties but is scarce and very expensive. It may be that fish oil is equally good.

Palm and shea oil have both been studied in Côte d'Ivoire but suffer from the fact that they are very viscous, making them difficult to apply, and giving rise to efflorescence.

(c) Plant juices

The juice of the euphoribia lactea is very well known in tropical countries. It can be used to protect earth walls but is absolutely essential to add it to lime (precipitation). The juices of the agave and opuntia cactuses can be used but they are extremely poisonous and can harm the eyes.

In Benin, Burkina Faso and Southern Ghana a red plant extract known as am is employed. In Northern Nigeria Iaso is used, which is an extract from a local vine called dafara (vitis pallide). Makuba is also used, this being an extract from carob-bean husks.

Banana juice can be used, but it must be boiled for a long time, consuming large amounts of fuel in the process; and there is no gurantee of it being effective.

(d) Other natural products

Paints can also be made from cream cheese (six parts) mixed with one part of quicklime and greatly diluted in water, or from whey, with 4 l of whey added to 2 kg of white cement. These formulations have been developed by the University of South Dakota.

(e) Soil

Earth slurries can be used indoors and fixatives added to them. Outside they are not lasting, but can be improved by stabilizing with mineral binders (lime, cements) or organic binders (bitumens, plant juices, and various oils), or with acids. Even when improved these emulsions must, in general, be regularly refreshed.

2. Transparent products

There is a strong trend towards the employment of products which aim at conserving earth indefinitely, while preserving the appearance of the material. Unfortunately earth is a support very different from other industrial materials, and the results obtained with these "magic" products are, to say the least, random, as real conditions are not the same as those in the laboratory. Numerous problems appear after a period of years.

The chemistry and the composition of the products are highly complex. It is advisable to carry out preliminary tests with a view to ensuring their effectiveness, at least in the medium term and for fairly harsh outside conditions. Many of these products, described as "totally waterproof", can resist only a low pore water pressure. Generally speaking, such transparent products help to

reduce the deterioration of the wall at the wearing coat. Their quality depends on the depth of penetration (up to at least 2 cm). These products may form a crust of treated soil, which has the effect of producing the disaggregation of the wall. This happens with sodium silicate and silicones in general.

With knowledge of these products - whether based on paraffin, wax, resin, or various minerals - as it stands, their use is best limited to a treatment of the finishing course of thick renderings and on sheltered walls.

(a) Surface water repellents

Silicons in a volatile solution require a suitably dry surface and their use is limited by the size of cracks, as these may not exceed 0.15 mm, especially on exposed walls. The only use for which they should be contemplated is for finishing renderings.

Silicons in an aqueous solution or emulsion can accommodate themselves to a certain moisteness of the support, although the same reservations must be made as above.

Metallic sopas, stearates, and polyoleofins must first be made the subject of special attention.

Fluates, or more scientifically fluorosilicates, form an artificial calacine by reacting with the calcium carbonate. They have absolutely no effect on soils stabilized with lime. They may be used with good effect on carbonated renderings using lime mortars.

(b) Resin-based film-forming impregnation treatments

These may offer an attractive solution for sheltered outside walls if they can be strongly absorbed into the first few centimetres of the soil and if they do not form a thick surface crust. Checks should be made to ensure that permeability to water vapour is maintained and that the impregnation can be refreshed.

(c) Water-proofing coatings

These products are based on resins in an organic solution or dispersed in water. Their efficiency is limited by cracks which may exist or appear in the support. The risk of blistering and deficiencies in permeability to water vapour makes their use highly unpredictable. They should in principle be avoided.

E. Whitewashes

Limewashes made from non-hydraulic lime have been widely used in many regions since time immemorial. They represent a fairly cheap way of affording protection against the harmful effects of rain, particularly in the absense of sophisticated materials and where budgets are subject to severe restrictions. These limewashes are most suitable for affording protection indoors or on sheltered walls outside. They can, however, be easily improved so that they last several years.

1. Drawbacks

Limewashes are not particularly durable because they are easily washed off. The simplest must be refreshed periodically (once or twice a year), particularly in wet climates. Additives can make very significant improvements to them. These include vegetable drying-oils (linseed oil, nut oils, castor oil, croton oil, and hemp oil), glues, casein, salts which are more or less hydrated (zinc sulphate, potassium alum, sodium chloride), resins or oleo-resins and rubbers or water-soluble rubber resins. Such limewashes are also very sensitive to mechanical shock and only offter limited protection to abrasion.

2. Benefits

Limewashes made from non-hydraulic lime are cheap and stand up fairly well to alkalinity as well as bitumen exudations (on walls stabilized in bitumen). Light in colour, they reflect solar radiation. They can be easily tinted with oxides. They can be easily and quickly applied and do not require specialized labour to apply them, although they must be applied with care.

Refreshing them is easy and their aging causes no major deficiencies in the support. The periodic refreshment rejuvenates the structure.

They have the advantage of regulating the moisture balance between the support and its surroundings. Because of their constituents (quicklime or slaked lime, salts, formaldehyde), they have certain antiseptic properties. They bring light and hygiene to what would otherwise often be miserable and unhealthy slums.

3. Binder

The best results are obtained with non-hydraulic lime slaked in paste, using high yield, finely sieved quicklime. The wash is prepared a few days before application. Commercial slaked lime can also be used on condition that it is not too far in carbonation. The content of calcium and magnesium oxides should not be lower than 80 per cent, while the carbon dioxide content should not be higher than 5 per cent.

4. Preparation of the binder

The containers or trenches used for slaking quicklime should be considerably larger than the original quantity as the material increases greatly in volume (as much as double). Attention should also be paid to the risk of burning as slaking quicklime generates high temperatures (120 to 130^{o}). The operation is best carried out at night when it is cool, with plenty of clean water available. All lumps are broken up and the lime mixed well until a uniform paste is obtained, which is brought to the desired consistency by adding suitable amounts of water. If slaked lime is used, the quality of the sieving should be checked. The basic mixture is one volume of slaked lime to one volume of water. It may be necessary to add water to obtain the desired consistency.

5. Application

The limewash is applied to a clean, dust-free surface, which should be free of all crumbling, in at least two coats (three or four coats being preferable). The first coat will be thin, but subsequent coats will be increasingly thicker. A distemper brush can be used for the first coat, while for the second coat a broom can be used, and even a yard brush is suitable for the later coats. The distemper is applied when the wall is in the shadow and extremes of heat or cold should be avoided. Precautions should also be taken to avoid showers, which could wash the whitewash off the wall. The best method is al fresco but this is very difficult to carry out on earth walls. Application to the dry surface will thus be the most common method used and care should be taken to moisten the surface, preferably with clean milk of lime, but without soaking the surface. Excessively thick coats will flake off. Drying should be slow.

6. Simple test

A block is weighed in advance and then given two coats of limewash. The block is immersed in water for two days and then weighed again. If the difference in weight is of the order of a few tens of grams the limewash is good. If the difference is of the order of several hundred of grams the limewash should be rejected.

7. Fillers

Fillers are additives to the binders which give the limeash properties which the binder alone could not give it. The fillers discussed below are all compatible with lime.

(a) Linseed oil

This increases the ability of the whitewash to stand up to variations in humidity and improves adhesion to the support. It should be added immediately before application.

(b) Tallow

This is animal fat composed of glycerides which gives greater plasticity when applying the limewash, by increasing water resistance and adhesion. Add about 10 per cent by weight of molten tallow to the lime. Tallow can be replaced by calcium stearate of linseed oil.

(c) Skim milk or whey

This increases the impermeability of the limewash. Add 1 part to 10-day-old skim milk or whey to 10 parts of water used in the preparation of the whitewash, immediately before use.

(d) Casein glue

In powder form, this is known as "cold glue". It acts as a fixative. The addition of formalin increases its strength. Dissolve this glue in boiling water until it becomes soft (2 hours) at the rate of 2.5 kg of glue to 7 l of water.

(e) Animal glues

These improve the adhesion of limewash. They include glues made from skin and from bones.

(f) Rye flour

This forms a vegetable glue soluble in warm water. It requires the addition of zinc sulphate as a preservative when it is in paste form. It increases surface hardness and resistance to rubbing.

(g) Alum

This is the double sulphate of potassium and hydrated aluminium. A small quantity in the form of a paste made by grinding and then boiling in water for a period of one hour is added to the wash immediately before use. It increases workability, surface hardness and resistance to rubbing.

(h) Sodium chloride

Common salt, it retains moisture in the limewash and facilitates the carbonation of the lime. It should be added slowly to the limewash prior to use. Calcium salts and trisodium phosphate (Na_3PO_4) are also used.

(i) Formaldehyde

This has the antiseptic and stabilizing properties of urea-formaldehyde. Disssolve it in water and add slowly to a mixture of lime and casein glue or lime and trisodium phosphate. It does not keep well.

(j) Molasses

This is a syrup residue remaining after the crystallization of sugar. 0.2 per cent by weight added to lime speeds carbonation and increases strength.

(k) Mineral fillers

These are inert fillers or soil (kaolin).

(l) Colourings

Exclusively minerals, in the form of moistened powders, they should be added prior to use.

F. Slurries

(a) Cement-washes and hydraulic lime-washes

Simple washes of cement or hydraulic lime give good protection and improved durability to earth walls. They are generally feasible when little money is available. They are not affected by the alkalinity of the wall. In good conditions of execution, they can help to reduce the quantity of stabilizer in the bulk of the wall. This type of wash requires a humid environment when hardening and thus curing must be carefully supervised.

They are more difficult to apply than the lime-washes based on non-hydraulic limes. As cement and hydraulic lime are more finely ground than non-hydraulic lime, the water requirement should be reduced, with a cement/water ratio of the order of 1 to 1.5 compared to 0.78 for non-hydraulic lime. As a result workability and covering capacity are less.

These washes are fairly resistant to the passage of water vapour and are therefore only suitable for use in regions where water vapour migration from the inside to the outside is not a problem (i.e. excellent in sub-tropical regions). They have a limited lifetime, between 5 and 10 years (on stabilized walls), and therefore require periodic refreshment.

Paints based on white cements also exist and are available in various colours. These paints, which contain additives to improve their plasticity, are only suitable for walls in stabilized earth and for very strong walls, but even here the results are rarely satisfactory. On weak walls, cement paints should not be used because of flaking and blistering.

Generally speaking, when it is intended to give stabilized walls a cement-wash or hyrdraulic lime-wash finish, they should be prepared with care (holes and cracks filled, dust removed) and thoroughly wetted. This moistening is indispensable when the mixture contains no calcium chloride (a salt which retains water), the use of which is justified in hot and dry regions (not more than 5 per cent of the mixture). Moistening facilitates application and prevents excessively rapid hydraulic shrink but may reduce the impermeability of the wash. The addition of hydraulic lime to the cement (maximum 25 per cent) does nothing for the wash but makes application easier due to improved plasticity.

Washes in cement or hydraulic lime should be applied in at least two coats, each 1 to 1.5 mm thick. Three or four coats are even better. The first coat should be applied with a brush that is not too hard, while subsequent coats can be applied with a broom or spray-gun.

If the surface is smooth, a thinned coat should first be applied to serve as a size or primer for a subsequent thicker coat. The reverse applies if the surface is rough. The wash should be applied when the wall is in shadow. Once the last coat has dried, it should be moistened in order to hydrate the cement and moistened again just before nightfall. The second coat is best applied at the earliest 12 hours after the first, and if at all possible 24 hours later, after moistening the first coat again.

Washes should be used within two hours of their preparation. Leftovers should never be used on the following day.

Colourings (3 to 7 per cent of various oxides) or water repellents can be added, though this should be done in the last coat. The water repellent can be 2 per cent of calcium stearate solution added to the cement, or 2 per cent of copper sulphate solution in a concentration of 100 gm to 10 litres of water.

A poorly applied cement-wash to a badly prepared wall will have the tendency to peel, flake, blister, and lose all its protective power, not to mention the shabby appearance it will give to the building.

Two formulations may be considered:

(a) One hundred parts of Portland cement should be mixed with 50 parts of silica sand or any other hard fine sand. Calcium chloride should equal 4 per cent of the quantity of calcium stearate equal to 2 per cent by volume of the cement. The sand is mixed in after first mixing the cement, the calcium chloride and the calcium stearate. The volume of water is more or less equal to the volume of cement, although this may vary according to site conditions.

(b) Slurry made lateritic soil, cement and water (Côte d'Ivoire). Two 50-l borrows of lateritic soil and one bag of cement are mixed with 175 l of water. The slurry covers at a rate of 2.5 kg per m^2, or in other words 340 g of cement per m^2: which is very economical.

(b) Bitumen washes

Perfectly dry earth walls with well-prepared surfaces (harshness rubbed down, brushed, and dust removed) can be protected by a coating of bituminous products such as emulsion, cut-back, "Flintkote", and so on. Local climatic conditions are very important as these products are more or less impermeable to water vapour. Moreover, the effectiveness of bituminous products for surface treatments is not very prolonged and care must be taken to ensure that periodical refreshment is carried out. Nevertheless these bituminous washes are among the least expensive and greatly improve the resistance to water erosion and surface abrasion of earth walls.

A precondition to the success of these bituminous coatings is the dryness of the ground to which they are applied. If the ground is moist, blisters and bubbles will soon appear leading quickly to the detachment of the coating and, even worse, the loss of material.

Bituminous coatings are often resisted because of their sombre colour - black. This drawback can be cured by treating them with a finish. This finish may be coats of paint or cement or lime-based washes. Such finishes should be applied several months after the treatment of the bitumen wall so that any defects in the bitumen coating become apparent and in order to avoid bitumen exudations. Applications of a paint finish, particularly oil-based paints, to a bitumen-stabilized wall or a wall which has been given a bitumen coating, must be preceded by the application of an undercoat of bitumen-based aluminium paint. This paint is compatible with the emulsion of the wall: the flakes of aluminium in the paint spread and cover the wall, preventing any exudation of bitumen from the wall.

Other treatments which can be immediately applied can also be considered. These include sanding with washed sand on the fresh bitumen coating.

Study of these finishes for bitumen-stabilized walls has shown that generally speaking products applied with a brush, such as milk of lime, bitumen emulsions, polyvinyl acetate, and styrene emulsions, remain highly permeable to water but hold back bitumen exudation.

Distemper paints and alkyd emulsions are not advisable. Oil-based paints stand up well to water but not to exudation. Bitumen paints are satisfactory from both points of view.

Three formulations may be considered:

(a) Paint based on coal-tar: one volume of Portland cement, with one volume of petrol, and four volumes of coal-tar. The tar does not have to be preheated. The cement and paraffin are mixed first and the tar is then added to them. The mixture is applied with a coarse brush to a fine primer coat made of a mixture of water and gas tar. The colour is black.

(b) A liquid bitumen wash can be produced from two volumes of coarse benzol and one volume of bitumen dissolved in the benzoline, to which a small amount of resin and quicklime has been added. Apply with a brush or fine spray. This wash gives a brown colour.

(c) A wash can also be prepared from 25 kg of preheated asphalt and 50 l of petroleum oil. The asphalt is added little by little to the oil and carefully mixed until totally dissolved. Once the mixture has cooled, it is poured through a fine strainer into another container in order to eliminate any undissolved materials and foreign bodies. It can be applied with a pesticide spray at a rate of 100 m^2 per day per person. The colour is dark grey. A finishing coat in milk of lime to which an animal glue has been added gets rid of any undesirable colour.

III. DETAILED ASPECTS OF SURFACE PROTECTION

A. Lathing and anchoring

1. Glue

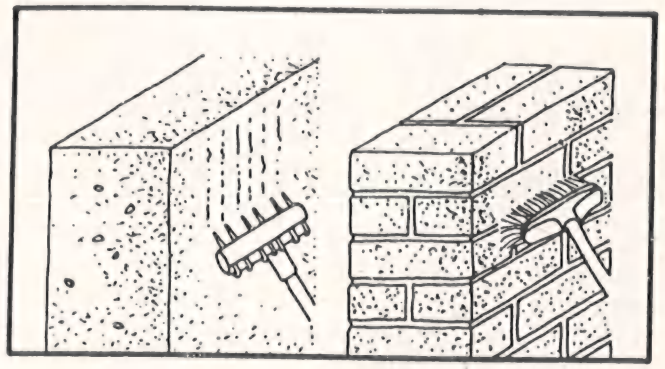
(Supports 1, 2, 4, 5.)

SUPPORTS					
MONOLITHIC			BRICKWORK		
SMOOTH LIKE RAMMED EARTH	POROUS LIKE COB	VERY POROUS LIKE STRAW-CLAY	SMOOTH LIKE BLOCKS	POROUS LIKE ADOBE	VERY POROUS LIKE SOD
1	2	3	4	5	6

The use of white joinery glue (dilute polyvinyl acetate) has been tested in Egypt, Nigeria, Sri Lanka and Sudan. This glue, diluted in water, is applied in two layers using a brush. Dust is fixed and the adhesion of the mortar of the rendering is facilitated. This glue surface treatment should by preference be used in conjunction with a fibre-reinforced rendering. Other dust fixatives can be used if they are compatible with the rendering.

2. Scrapping and dust removal

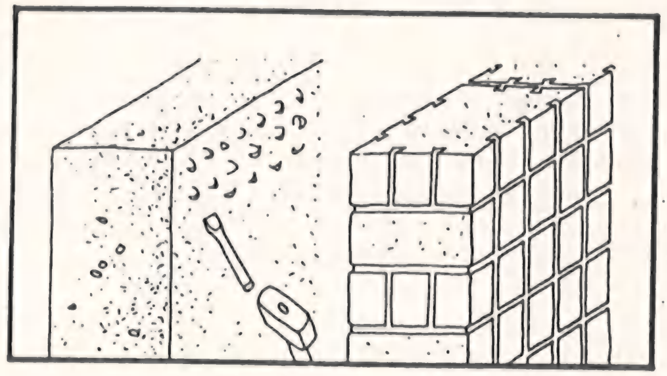
(Supports 1, 2, 4, 5.)



Scrapping the supports is particulary important where they are at all crumbly, as this makes it possible to remove any materials lacking cohesion or which are not well fixed. On rammed earth, this exposes the sand and gravel skeleton holding the rendering. Dust removal is indispensable on the majority of earth supports. It can be done with a brush, when dry or when moist (without saturating the wall) or using compressed air blowers.

3. Grooving

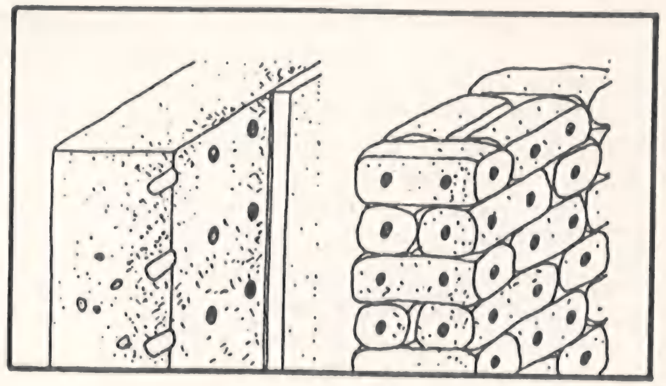
(Supports 1, 2, 4, 5.)



On walls built in compressed blocks and adobes, the joints are scraped to a depth of 2 to 3 cm and the rendering is anchored by the hollowed-out joints. The blocks can themselves be grooved or chiselled. Grooving is a good way of ensuring anchoring on rammed earth and cob. The grooved surface can also be prefabricated with special moulds for blocks and formwork fitted with nailed, dovetailed battens for rammed earth.

4. Holes

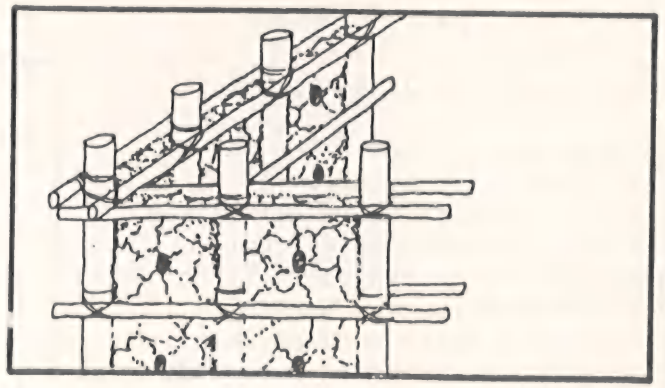
(Supports 1, 2, 3, 4, 5, 6.)



This anchoring technique is particularly suitable for rammed earth, cob and straw-clay supports. It involves making slanting holes when the material is still moist or the formwork has just been removed. The holes should be at least 3 cm and preferably 6 cm deep. When building in balls or loaves of soil, the holes are made in the fresh material.

5. Piercing walls

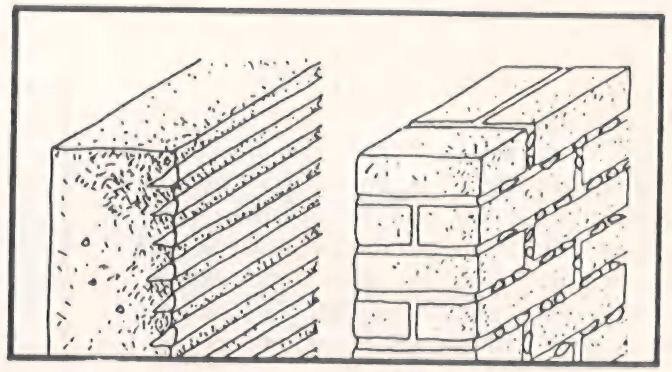
(Supports 2, 3.)



This procedure is used in Gabon on houses built in cob between posts. The masses of a clayey soil covering the netting are pierced with a dagger from one side to the other. The rendering is applied on both the inside and the outside and the two layers are united by a sort of bridge of rendering.

6. Anchor points

(Supports 1, 2, 3, 4, 5, 6.)

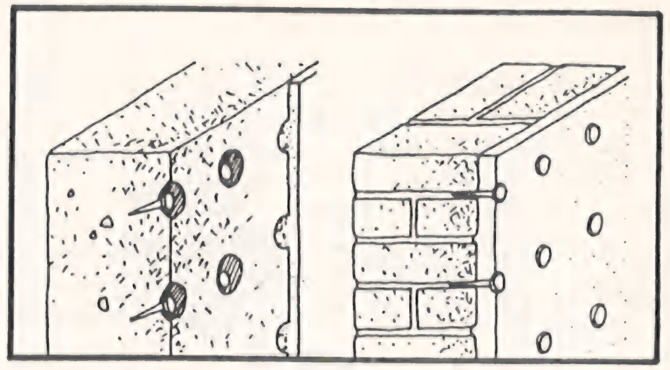


The wall is encrusted with solid fragments, flakes of stone or broken pottery. This encrusing can be easily carried out on fresh cob, or even on daub. The fragments are set obliquely. On blockwork or adobe walls, the fragments are inserted into the fresh mortar. Anchoring points of the same composition as the rendering can also be provided, e.g., strips of lime included in outer thickness of rammed earth.

7. Nailing

(Supports 1, 2, 4, 5.)

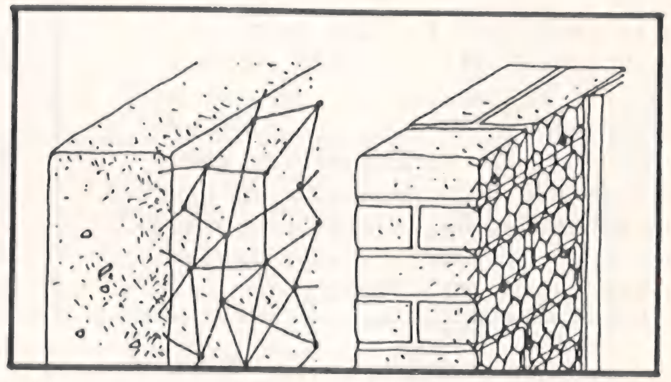
The nails should preferably be galvanized and long (at least 8 cm), with wide flat heads. They are inserted in the wall in a regular pattern, with about 10 to 15 cm between each nail. As they can hinder the application of the rendering another method is to make holes in which the nails are placed so that they are level with the support, or to insert the nails after the application of the floating coat.



8. Lattice work

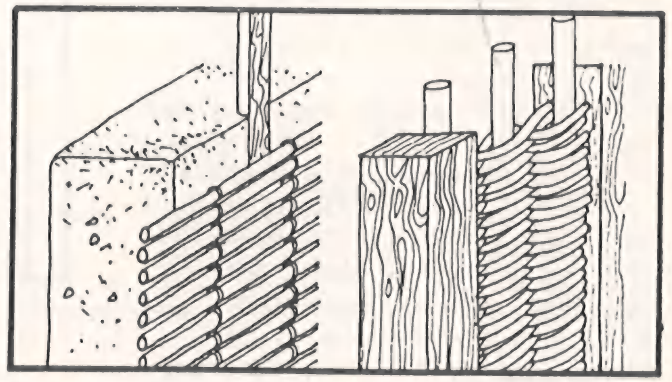
(Supports 1, 2, 3, 4, 5, 6.)

Conventional chicken wire can be used (hexagonal holes). It is best if the netting is galvanized for walls exposed to weather, although non-galvanized netting adheres better. The netting is fixed by nails twisted into the mesh and nailed in a regular triangular pattern. Steel wire can be woven on to nails driven into the wall.



9. Wattle

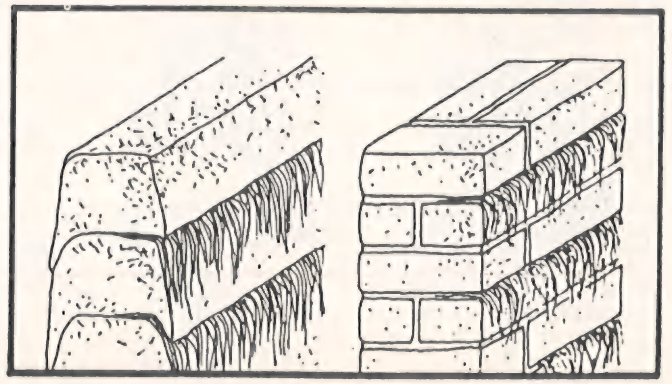
Some techniques leave the wattle exposed. This is the case for daub or cob on posts, or even rammed earth between reed formwork. Sometimes this is also done with heavy clay-straw, which is covered with plaited canes or woven reeds to anchor the rendering.



10. Fibres

(Supports 2, 4, 5.)

The University of Nairobi has tested a wall protection which combines cement and sisal fibres. The mixture is applied as a first coat and the short sisal fibres remain visible, facilitating the adhesion of the subsequent coats. Instead of sisal, other natural fibres (coir, hemp, etc.) sysnthetic fibres (poly-propylene), animal hair, or wooven materials (jute sacking) can be used.



B. Finishes and decorations

Apart from their function as wall protection, both indoors and outdoors, surface coatings play a decorative architectural role. This aspect of the rendering in finishing and decorating building is apparent in many countries and has long been exploited. It includes customary techniques and motions just as much as the texture or grain of the finishing coat, reliefs worked in the bulk of the wall, colour, and flashing with various other materials. Finishes of the visible rendering are applied manually, either with traditional masonry tools, trowel, hawk, drag, etc., or mechanically with blowing machinery.

The various treatments are carried out either before hardening (float-finished or rustic renderings), or after hardening (e.g., scraped or glazed renderings).

(a) Smooth finish

This is usually used indoors. The finish is smoothed with the laying-on trowel and the float.

(b) Dragged finish

The floated surface is scraped after hardening with a metal blade, or with a devil float, (i.e., a float with steel nails protruding from its bottom). Once the rendering is dry, the dust can be removed with compressed air or by hosing down.

(c) Rustic finish

The rendering is applied by the trowelful, each covering the previous one. When slapped on with the trowel the rendering has a scattered irregular grain.

(d) Crainy finish

The rendering has a rough appearance resulting from being thrown or blown on (Tyrolean, fine sand, or plaster blowing equipment). This method reduces cracking.

(e) Crushed rustic

The wall is first given a grainy finish and then crushed with a float or flattening tool.

(f) Whipped finish

The freshly applied rendering is whipped with a broom or with flexible fibres (E.g., palm twigs).

(g) Aggregate finish

Coarse sand, small stones, stone chippings, or shells are thrown against the fresh rendering. The pebble cash finish is well-known for its ability to reduce cracking.

IV. TESTS ON RENDERINGS

Numerous standardized tests exist which attempt to test the quality of renderings, and especially the behaviour of the inseparable support-rendering complex. The object of the tests is thus basically to find a rendering the behaviour of which will be acceptable, in time, for a specified support and in relation to a number of performance criteria selected by the user (e.g., frequency of maintenance, resistance to climatic and mechanical agents).

A. Small-scale tests

These tests can be useful but are of limited application because they do not consider the rendered wall as a whole and concentrate on fragments. Although scientific, these tests come nowhere near to approximating real conditions.

1. Open porosity

First of all the sample is dried by dry air or stove until it attains a constant weight. It is then completely submerged by any of various procedures and superficially dried with moist cloth and weighed. Porosity is expressed as a percentage according to the relationship:

$$\frac{P^1 - P}{P} \times 100$$

(Where P = dry weight; P^1 = absorbed weight of water).

2. Moisture content

This is measured either on the basis of the resistivity of the material with an apparatus equipped with two electrodes which are placed in the rendering, or with a sort of flat capacitor, which is applied to the rendering and gives a direct reading on a gauge.

3. Absorption capacity

Water is forced into the surface of the rendering under pressure. The quantity of water crossing a predetermined area during a given time is recorded by means of a flat chamber held in place by means of a waterproof putty and connected to a recipient of fixed level (in order to ensure constant pressure). A rendered block can also be completely immersed in water and the difference in weight before and after immersion determined.

4. Erosion

This test involves spraying with a jet of water or dripping water on to the material.

5. Adhesion tests

Adhesion is measured by means of a dynamometer with gaiters which is used to tear loose a 50 mm pellet from the surface of the rendering after first cutting it free with a corer to a depth slightly more than that of the rendering. The pellet is glued to a metal disc with a suitable glue. Adhesion is good if breaking occurs in the rendering; it is not good if it takes place at the rendering-support interface.

Yet another test for the adhesion of rendering to rammed earth has been tried in Morocco. A porous cement block is stuck to a sample of rendered rammed earth, and tensile force exerted on a ring located in the axis of the block. The test is for an adhesion between rendering and rammed earth of 1 kg per cm^2.

B. Large-scale tests

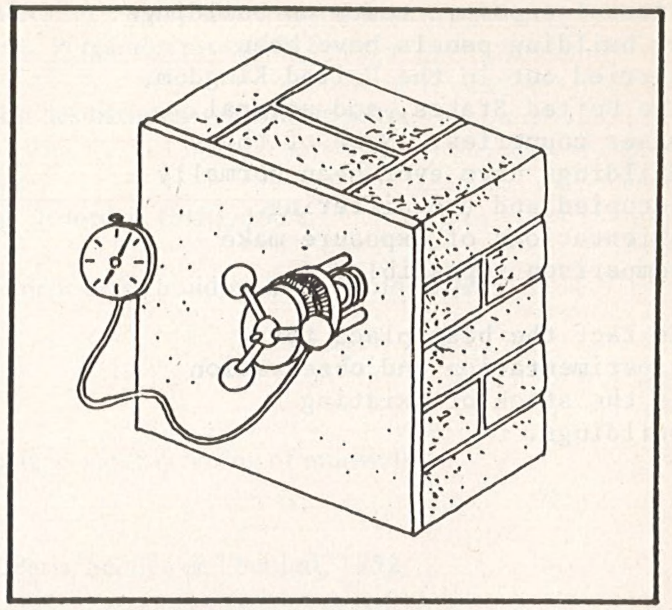
1. Accelerated aging

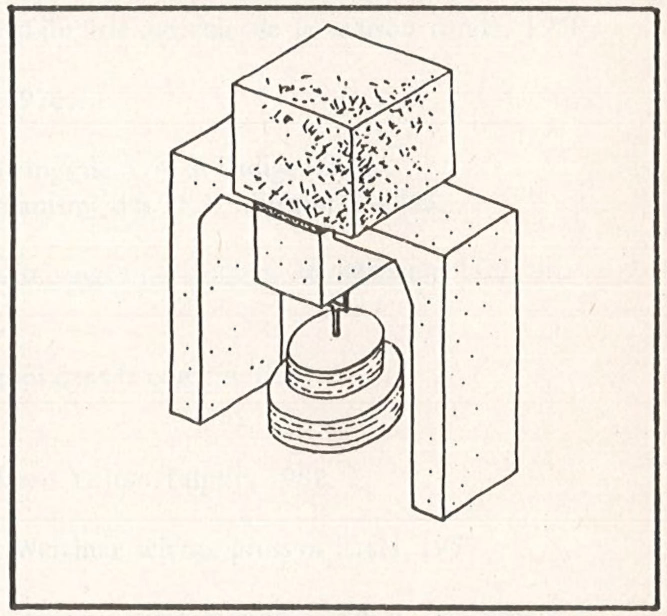
This test should reflect local climatic conditions as far as possible. The aging cycle by exposure to heat, rain and frost must be defined by the proper interpretation of the tests as it is a matter of guaging the responses to stresses rather than determining a state after aging.

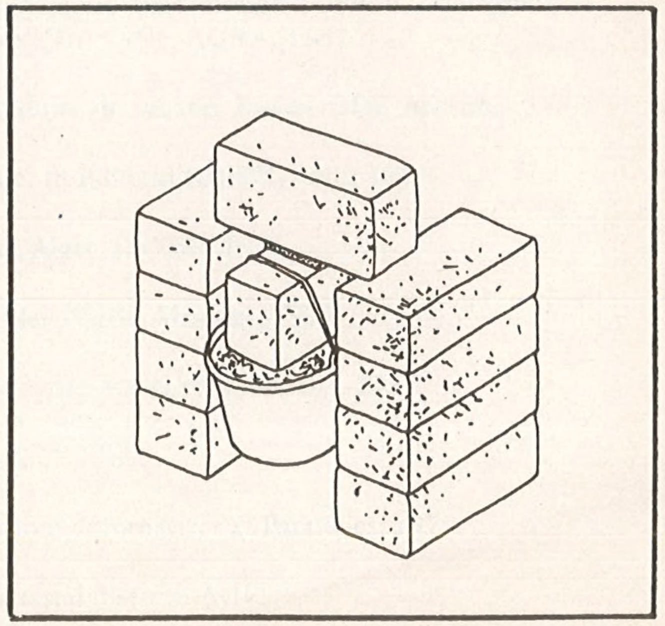
2. Natural aging

The behaviour of renderings with time is observed on small walls exposed to natural weather conditions. It is advisable to ensure that these test walls are properly oriented with respect to the prevailing rain and wind. This test has been tried in various countries, but has been carried out on a truly large scale in Senegal and in the United States and has been the object of study for several decades. Nevertheless the results are more accurate for perimeter walls than those of dwellings, as no examination can be made of the migrating water vapour which affects most renderings.

The test walls have a minimum exposed area of 1 m^2. They are subjected to the greatest climatic stresses in the region. They are covered with a waterproof cap projecting 10 cm on each side, and fitted with a drip. The test walls are separated from the ground by a footing at least 25 cm high and provided with anti-capillary barrier. The rendering comes to within 2 cm of the cap and reaches down to the footing, but does not touch it. At least one year and, more usually, two to three years, are required to arrive at the first conclusions which do not consider the disorders suffered at the edges of the test walls.







C. Building or building panels

Natural exposure tests on buildings or building panels have been carried out in the United Kingdom, the United States, and several other countries. None of these buildings have ever been normally occupied and the differing orientations of exposure make comparison impossible.

In fact the best place for experimentation and observation is the stock of existing buildings.

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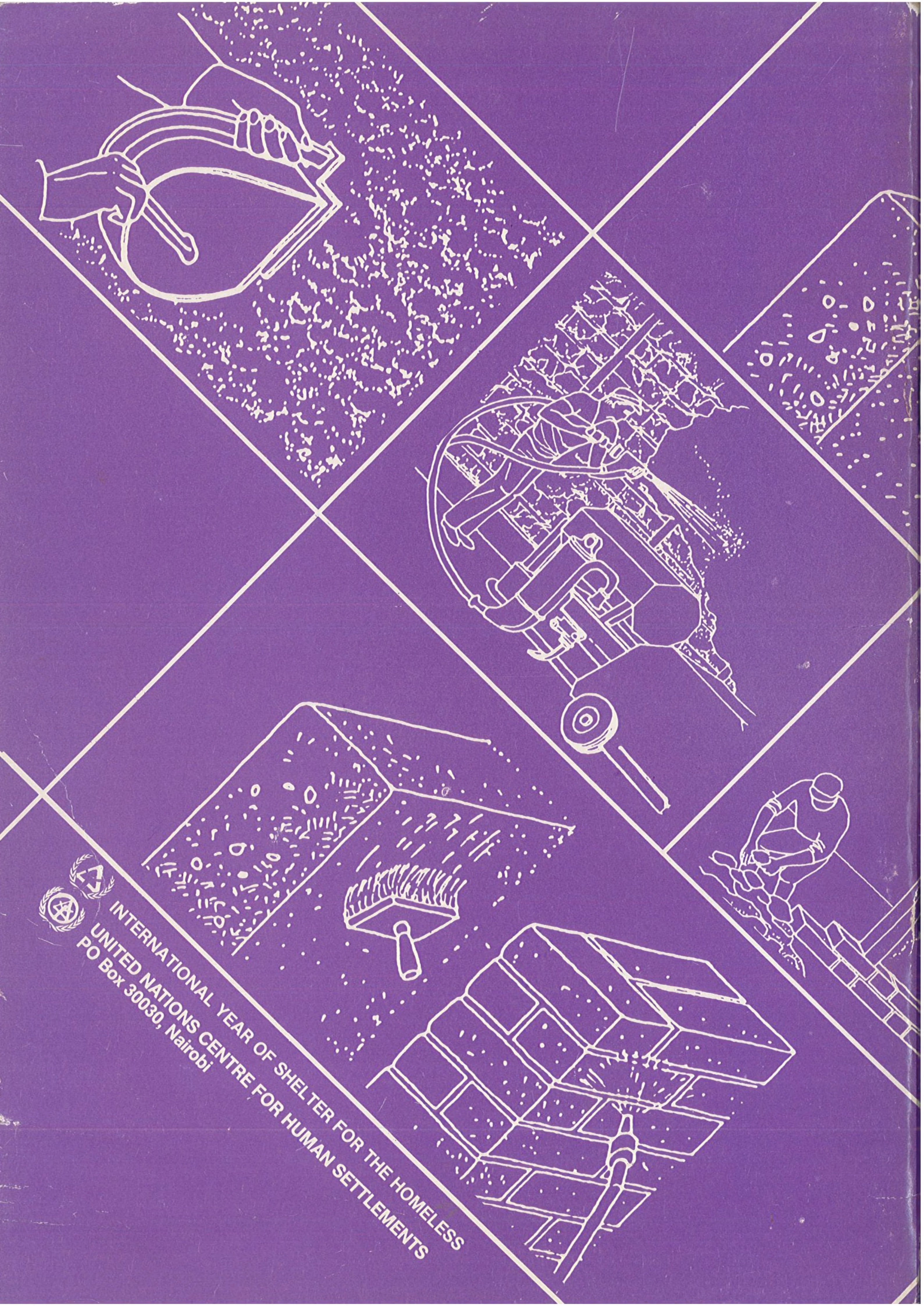

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